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Replication of micro laser textures by injection molding

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Abstract

Increasingly micro technology becomes more important in order to develop new products with high added value. These new technologies known as micro allow us manufacturing precision components; these new micro components should work and take carrying out the functions previously performed by larger parts. Microinjection is one of these new technologies. This has the capacity to produce parts, for different materials both plastic and metal and for some industries and applications. The main objective in this paper is to determine the replicate microtextures capability for plastic injection molds. For our samples, ABS plastic is injected into four aluminum cavities with different laser textures performed in, using different technologies to get them. In order to analyze how mold texture affects parts, optical interferometry technique was selected to measure it. The superficial topography obtained was processed using MountainsMap™ software, in order to get the replicability of injected parts. It has also been used an electron microscopy (SEM) to evaluate the mold textures and injected parts in a photographically way.

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Keywords: Replication; Injection Molding; Laser Machining; Textured.

1. Introduction

Microtechnologies popularity is increasing nowadays, in fact, demand for high-tech and multifunctional products are increasingly. Microtechnologies are trendy, with a high influence in all kind of markets such as aerospace, automotive, medical, equipment, etc.

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Thermoplastic injection is one of main technologies in the production high demand parts in microplastic components N Zhang et al. (2012) and B.-K. Lee et al. (2004), so the most important injection machinery companies are preparing their equipment in order to adapt them to mini and microinjection.

Micromachining, in recently years, is one of the fastest growing technologies; it allows the manufacturing of high precision microparts in a wide range of materials. In recent years has been a trend of incorporating several microtechnologies on the same machine in order to increase the performance of the machine without increasing the final price of the equipment.

The combination of these two technologies is useful for micromoulds manufacturing for plastic injection, which allows the manufacture of high precision microcomponents and in large series. Within this area it can be possible to find the micromachining by laser technologies Johan Meijer (2004). The laser machining technology is based on the generation of a high power laser beam that is oriented through the workpiece by a system of high precision mirrors. In the incidence area, beam is achieved by a high power density produced by the melting or volatilization of the material. The laser beam erodes the multilayer material obtained in this way, the geometry and required depth.

One of the great advantages of this technology is although to be a source of energy that is applied on the material, there are no wear, breakage or collision of the cutting tool, which is a great advantage compare to the process of traditional metal removal. The laser machining technology provides an alternative to molds texturing, saves machining time and reduce the need to apply chemical machining.

Laser process enables a reproduction of the texture of the molds, if necessary, because it can be possible to process digital information stored electronically by laser. This fact ensures an identical texturing in each mold and data to get it, can be send anywhere in the world.

2. Methodology

In this work is being trying to assess the ability of plastic to replicate textures obtained by laser micromachining techniques. Furthermore, we will try to analyze, how the injection parameters affect to replicate features.

2.1. Materials

In performed tests, have been injected Acrylonitrile Butadiene Styrene (ABS), MAGNUMTM 3453 from Magnum Company in black format. Its properties are specified in Table 1. It was decided to use this material with black colorant to make more easily subsequent measurement stages, in order to avoid the possible influence of color on measurement equipment.

For manufacture mold cavities, it was selected a high strength aluminum alloy EN AW 5083 widely used in the manufacture of plastic injection molds. This alloy has a high thermal conductivity and an easy machination, for this reason this alloy was selected for laser machining instead of a steel alloy.

2.2. Mold

It has been performed a four-cavity mold. In it has been combining chip removal machining and laser machining for textures machining. In a first stage, and from a reusable mold P. Hernandez (2005), is machined one square insert made of steel 1.1730 that put up four aluminum square cavities to inject and the plastic distribution channels. Therefore, the four cavities are formed by the steel machined plate and four alloy inserts of 10mm thick, removable to facilitate subsequent measurement step. After machining, the four aluminum cavities were texturized with three different textures, using laser technology.

<u>Texture of the cavity 1</u>

In the first insert, the texture was generated by a rectangular holes pattern, the holes are spacing a distance of 1 x 1 mm, this texture is made by holes formed in the displacement of the molten aluminum, Fig. 1. The outer diameter of the holes is 0.75 mm and the inner diameter is 0.23 mm with a depth of 100 microns.

The laser used for this texture was a diode laser Trumpf Trufiber 400 of single mode fiber continuous wave and 1070 nm wavelength. Have been used 100 W of power and scanning speed of 400 mm/s. To obtain the desired geometry, a total of 4 cycles were needed.

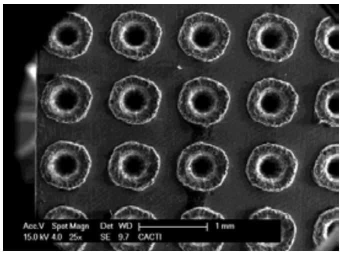


Fig. 1. Texture of the cavity 1

<u>Texture of the cavity 2 and 4</u>

In second and fourth insert, a pattern of micro-texture, formed by channels that are repeated in one direction with a spacing of 0.6 mm between them, was machined, Fig. 2. We used the same equipment, Trufiber Trumpf 400 single mode fiber, with a power of 100 W and speed of 300 mm/s.

Cavity 2 has 0.26 mm of height channels, elevations separation is about 0.19 mm and a valley width of 0.22 mm. The cavity 4 has almost the same height of 0.24 mm, the same spacing and 0,21mm of width. The difference between these two cavities is their positioning into the mold, to analyze the influence of the arrangement of the texture on the plastic front advance. For insert 2 the channels are arranged in the same direction of plastic advance front, while in the cavity 4 are arranged perpendicular to flow front.

a b

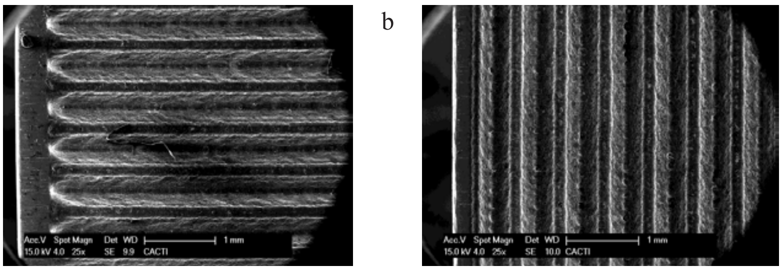


Fig. 2. (a) Texture of cavity 2; (b) Texture of cavity 4.

<u>Texture of the cavity 3</u>

The third insert was machined in a square mesh texture, with periodicity of 60x60µm. It was formed by the combination of holes and walls generated by a fusion-ablation process which allows the molten material to accumulate on the walls surrounding holes (PLD). The diameter of the holes is about 38 microns, with a depth of 50 microns, Fig. 3.

The laser used to achieve this texture was a Rofin PowerLine 20 SHG with source of Nd: YVO4 vanadate Q-Switch with wavelength of 532 nm and pulses in the range of tens of nanoseconds. To achieve the desired geometry has been used a scanning speed of 1200 mm/s with pulse repetition frequency of 20 kHz.

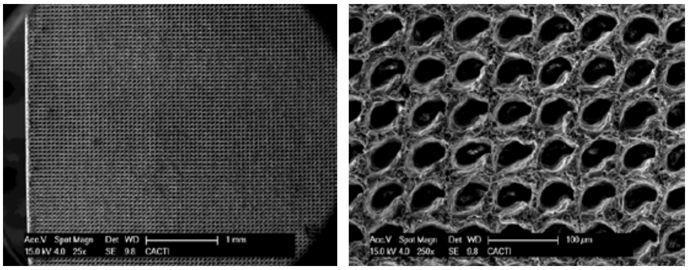


Fig. 3. Texture of cavity 3

2.3. Measurement equipment

In order to analyze the capability of replication for the ABS, on the textures machined, several images of the samples will be obtain for each experiment, in order to obtain a 3D topography of each sample, so to get it, we decided to use microscopy SEM and optical interferometry analysis technologies.

On a first way, a Philips XL30 microscope was used. Main features for this equipment are: resolution up to 3.5 nm, accelerating voltage: 0.2 - 30 kV (100 V step) and thermionic gun W.

To obtain the texture images of injected plastic parts, with the scanning microscope, it was needed a previously samples coating, for this measurement technology, with a thin layer of a conductor material, a technique known as sputtering, in this case with a thin layer of gold and then paint. Also it was needed a connecting track between metal support and conductor layer, this conexion was obtained by using silver paint.

Measuring surfaces were obtained in collaboration with the Nanotechnology and Surface Analysis of CACTI, University of Vigo, using a Wyko NT 1100 interferometric microscope with high resolution.

2.4. Experimental methodology

As we have previously proposed, in present study will attempt to analyze the ability of ABS to replicate textured surfaces, machined by laser technology and micro-textures. Also, we will try to analyze the influence of injection parameters in the replication capability.

Given the objectives of this study, in Table 1 are shown the matrix that determines the number of experiments and the value of the variables that correspond to each one.

Table 1. Experimental table.

Experiment	1	2	Material	Cavities
1	215ºC	65 cm^3/s	ABS	1,2,3,4
2	215ºC	85 cm^3/s	ABS	1,2,3,4
3	265ºC	65 cm^3/s	ABS	1,2,3,4
4	265ºC	85 cm^3/s	ABS	1,2,3,4

The experimental methodology consists in following steps:

Phase 1 - Plastic Injection

First phase in this study was injection, following the factors described previously and using for that an ENGEL Victory 28 machine. Six sets of parts per cycle were injected.

Phase 2 - Measurements

The sixth part obtained from each injection cycle was used for take measurements with a scanning electron microscopy (SEM) and for processing with optical interferometry, in order to subsequently analyze the replicability and observe quality of laser machining inserts.

Phase 3 - Getting Results

In SEM after spraying has taken 20 pictures of all variables, injected (16 images) and different inserts (4 images). The pictures of the samples topography was obtained by applying a SEM accelerating voltage of 15kV, and a spot value of 4. With these characteristics has been obtained 20 images of about 12 mm ² of the input casting surface. Also in cavity 3, due to its size, an extension to 100µm for a better analysis of topography was made.

20 parts were analyzed by optical interferometry, 4 metallic from mold and 16 ABS plastic parts injected. For each sample was obtained an image "stich", a result of the digital stitching of 217 individual images. The individual images are performed with the 5 X objectives, and with the intermediate lens FOV 1X. The size of each image "Stich" is about 29x5 mm2.

Images were also subsequently processed with 6.2 Premium MountainsMap™ software.

3. Results

3.1. Cavity 1

By analyzing the photographs obtained, Fig. 4, it was observed how plastic replicated the mold surface perfectly. One ring-shaped depression around a plastic castle is formed. This phenomenon is due to deposition of the molten material during the laser machining process. This effect has caused ejection problems of injected part.

As you can see a higher fill rate and injection temperature conditions, a better filling of machined holes has been obtained.

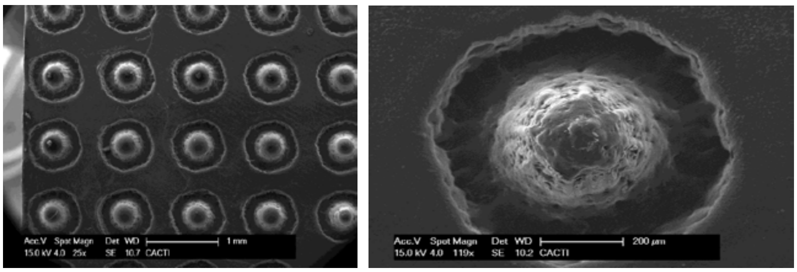


Fig. 4. Plastic part texture of cavity 1, 265ºC, 85cm^3/s

In the way to interferometry measurements at this point, data gaps happen, these are represented in the three-dimensional images as empty holes. By using MountainsMap these holes are covered with the aim to get the theoretical surface. Although the results are not quite accurate.

A similar trending was observed in pictures, getting higher replicability values by increasing temperature and fill rate.

3.2. Cavity 2 y 4

As can be observed in Fig. 5 and Fig. 6, quite good results are observed in longitudinal machining grooves, in terms of replicability. Surfaces obtained are much more homogeneous than the first point studied, although some differences are noticed between consecutive grooves, surely caused by the laser machining process.

If we analyze the results in terms of surface topography parameters (Table 2), we observed that the value of Sa (average surface roughness) best replicated values are obtained under conditions of maximum speed and high injection temperature.

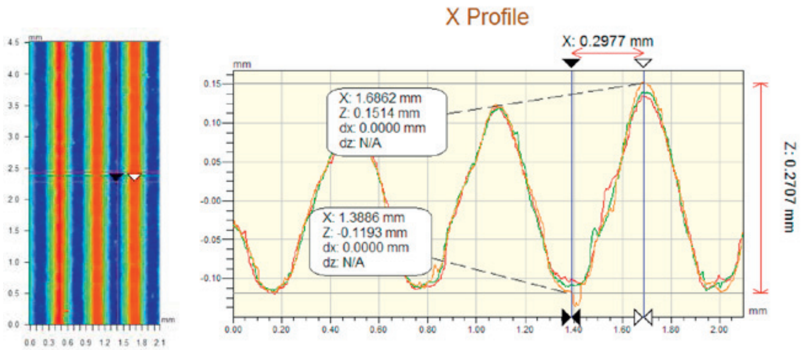


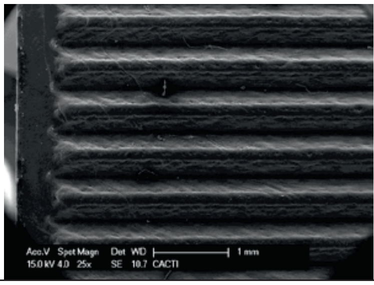
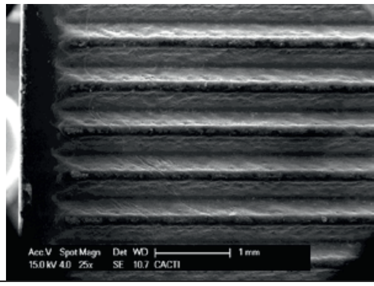
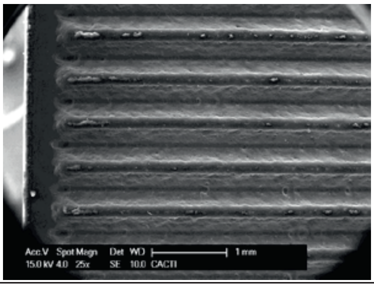
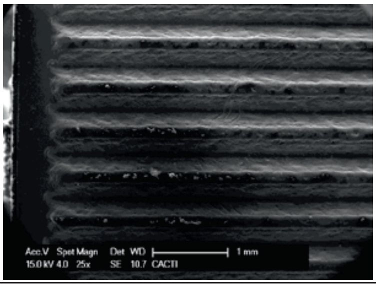
Fig. 5. Topographic sections in insert with texture 4.

Table 2. Roughness parameters of cavity2 and plastics parts injected.

Parameter	Cavity 2	215°C/65cm^3/s	265°C/85cm^3/s
Sa	72.4 µm	71.4 µm	72.0 µm
Sq	81.9 µm	82.2 µm	84.5 µm
Ssk	0.243	0.201	0.362
Sku	1.67	1.86	2.08

Table 3 shows results of analyzed pictures. In it we can see how plastic can copy texture easily; large differences in the different injection conditions haven't been observed.

Table 3. SEM of plastic part texture of cavity 4.

	65 cm^3/s	85 cm^3/s
215°C		
265°C		

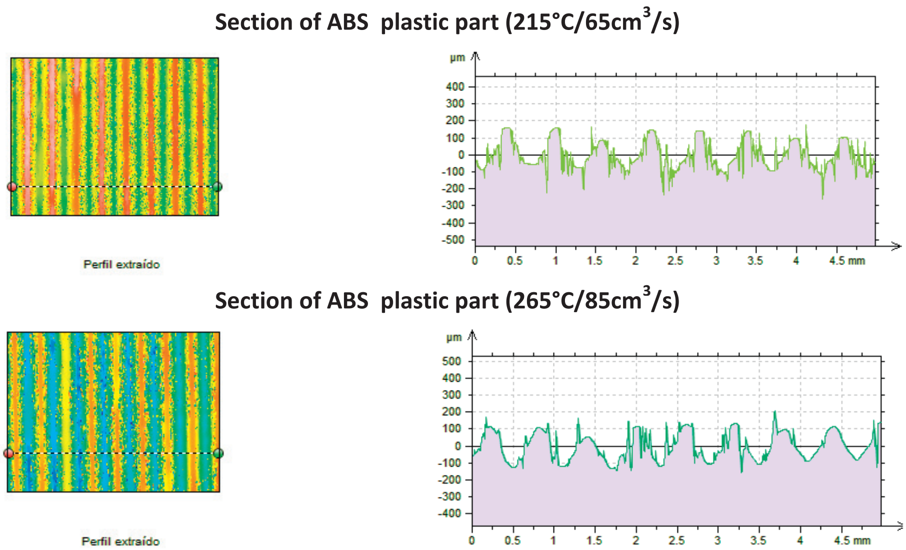


Fig. 6. Comparison of topographic sections in insert and plastic parts with texture 2.

If we analyze the results in terms of surface topography parameters, we observed that the value of Sa (average surface roughness) best replicated values are obtained under conditions of maximum speed and high injection temperature.

3.3. Cavity 3

The surface of the cavity 3 is more irregular and distorted, Fig. 6, 7. Fused material accumulation around holes walls is really asymmetric. Very dissimilar profiles are obtained; the dimensions and depth of holes don't repeat any sequence. The holes have different depths and widths.

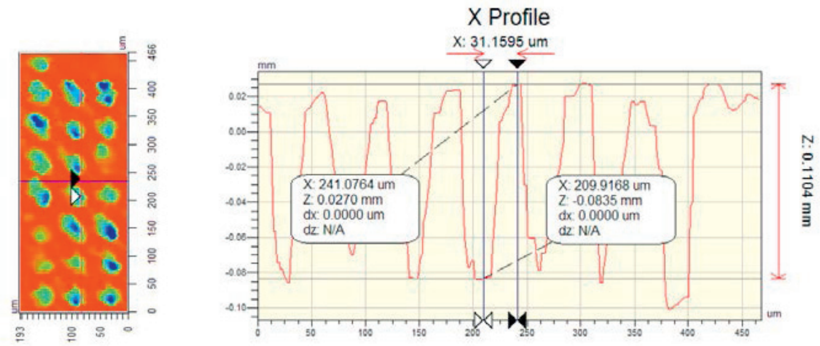


Fig. 7. Topographic sections in insert with texture 3.

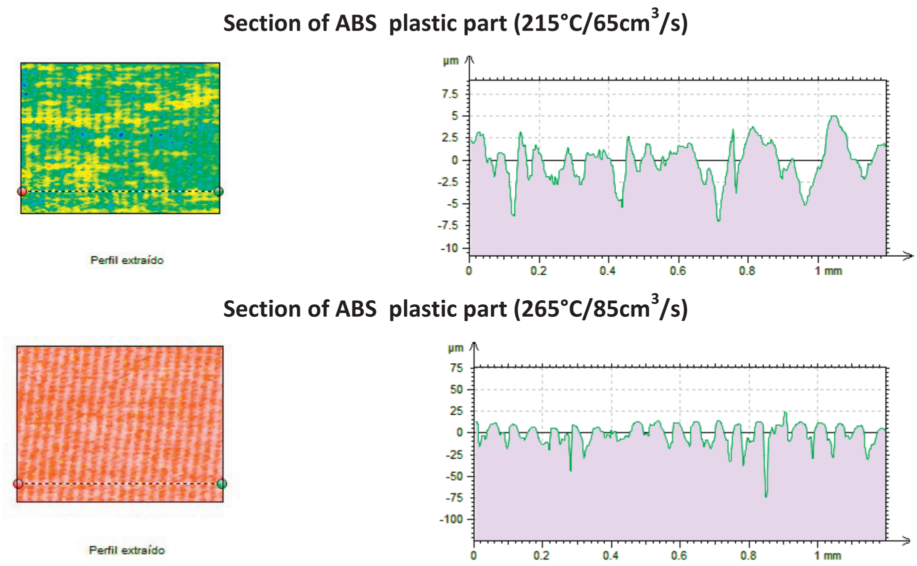
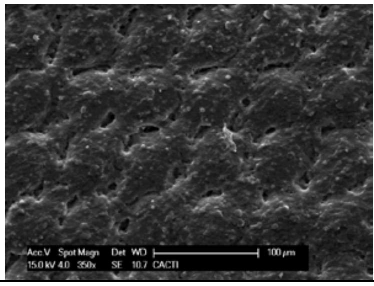
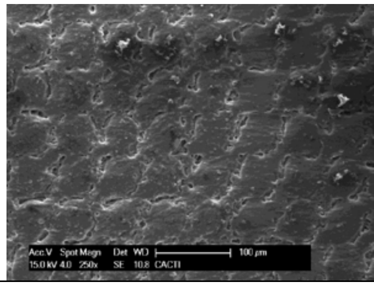
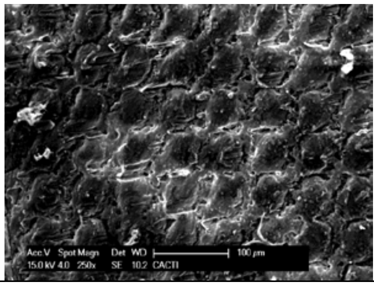
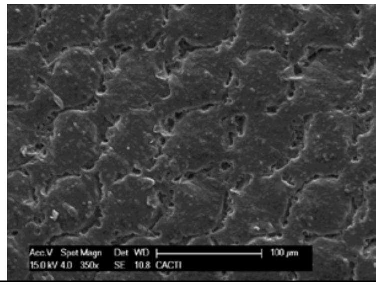


Fig. 8. Comparison of topographic sections in insert and plastic parts with texture 3.

Analyzing pictures obtained by SEM microscopy (Table 4), was observed that ABS has a lot of problems to introduce inside the holes, and therefore to replicates the texture.

Table 4. SEM of plastic part texture of cavity 3.

	65 cm^3/s	85 cm^3/s
215°C		
265°C		

If we analyze surface topography parameters (Table 5), we can observe that Sa value (average surface roughness) under conditions of high temperature and injection speed, get a little closer approaching to the initial values obtained in cavity measurement.

Table 5. Roughness parameters of cavity3 and plastics parts injected.

Parameter	Cavity 2	215°C/65cm^3/s	265°C/85cm^3/s
Sa	17.6 µm	2.37 µm	8.62 µm
Sq	24.1µm	3.09 µm	12.8 µm
Ssk	-1.81	-0.578	-3.32
Sku	6.00	4.19	27.3

4. Conclusions

Taking account results obtained by optical perfilometry and with microscopy, we can conclude that the textures corresponding to the cavity 2 and 4 are those that are better replicated by ABS. Also a better replication quality is got in the cavity in which texture has the same orientation as the advancing of flow front. By using this methodology, it was observed many replicability problems with texture 1 and especially with texture 3.

The first texture due to its pronounced peaks forces us to get up injection speed, modify the gate designed and change it to a sub gate or change the mold temperature. Cavity 3 texture is the most difficult to replicate, in any tests have been achieved desired texture, only at the highest temperature and speed tests have approached desired texture image, but far from its theoretical value.

This raises further studies, using the same methodology, modifying injected material in the way to analyze the influence of plastics in replicated capability and more and new modifications in injection parameters such as pressure or mold temperature.

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